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It has long been believed that the ascending currents above the thermal equator proceed immediately over the northeast and southeast trade-winds as southwest and northwest anti-trades. It is possible that part of the anti-trade sinks down over the high barometric pressure in the North and South Atlantic oceans and returns with the trade-winds, but the greater portion descends north and south of the origin of the trades and continues to the poles as the prevailing southwest or northwest winds of the North and South Temperate zones, respectively. The facts upon which this theory is based, as regards the Atlantic Ocean, are mainly observations upon the Peak of Teneriffe, where the southwest wind can be observed the whole year; and although it is lower in winter than in summer, there are no observations which prove that this anti-trade ever reaches the surface of the ocean.

The author, after he had made the first meteorological observations over the ocean, with kites flown from a transatlantic steamer in 1901, concluded that a vessel, which could be navigated at will, would enable meteorological data to be obtained with kites independently of the natural wind.[1] He suggested the application of this method to the exploration of the atmosphere in the trade-wind region at the Glasgow meeting of the British Association in 1901,[2] and at the Berlin Congress for Scientific Aëronautics in 1902.[3] In order to organize such an expedition, applications for aid were addressed in 1902 to the Prince of Monaco, and in 1903 to the Carnegie Institution, but without receiving the desired assistance. However, Professor Hergesell, President of the International Commission for Scientific Aëronautics, succeeded in interesting the Prince of Monaco in the scheme,

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[1] Science, **14**, 412 and 896.

[2] Report Brit. Ass. Adv. Sci., Glasgow, 1901, Transactions Section E.

[3] Protokoll der 3. Versammlung der Internationalen Kommission für wissenschaftliche Luftschiffahrt, Beilage 11.

and upon his yacht, the "Princesse-Alice," during the summer of 1904, kite-flights were made in the region bounded by Spain, the Azores, and the Canaries. Although a height exceeding that of the Peak of Teneriffe was attained several times, the southwest current, which had been reported on this mountain, was not found. Thereupon Professor Hergersell stated that he believed this current was due to the disturbing influence of the island, and that in the region explored the interchange of air takes place through the northwest current, which he had observed.[4]

These conclusions, which involved a fundamental principle of meteorology, namely, the existence of the upper return-trades, seemed to demand further investigation, and accordingly M. Teisserenc de Bort and the writer undertook to execute this through their assistants, Messrs. Maurice of Trappes Observatory and Clayton of Blue Hill Observatory. Mr. Clayton made the voyage from Boston to Gibraltar, via the Azores, in June, 1905, on the White Star steamer "Romanic," and flew kites six times to an average height of about 1000 meters. The steam-yacht "Otaria," of 350 tons, purchased and equipped by M. Teisserenc de Bort for exploring the atmosphere, and having on board Messrs. Maurice and Clayton as the scientific staff, went during the months of July and August, 1905, at the mutual expense of her owner and the writer, from the Mediterranean, via Madeira, the Canary and Cape Verde islands, to latitude 10° north, longitude 30° west, returning via the Azores and Corunna (Spain) to Havre. Seventeen kite-flights were made over the ocean besides two in the harbor of Santa Cruz (Teneriffe) to study the sea-breeze, and another off Corunna (Spain) during the total solar eclipse of August 30, 1905. In this way continuous records of barometric pressure, air-temperature, relative humidity, and wind-velocity were obtained from sea-level up to the extreme height of 2200 meters, although wind-velocity was recorded to an altitude of 3100 meters. The direction of the wind was obtained by measuring the azimuth of the kites. Direct observations were made by Mr. Clayton upon the Peak of Teyde (Teneriffe) to a height of 3700 meters, and upon the Peak of Fogo (Cape Verdes) to 2200 meters, and observations of clouds enabled the wind to be ascertained about 500 meters higher. To attain a greater height in the free air than was possible with kites, the "Otaria" was provided with large paper balloons, eleven of which, filled with hydrogen gas, were liberated from the islands of St. Michaels (Azores), Madeira,

[4] Conférence de la Commission Internationale pour l'Aérostation Scientifique, St. Pétersbourg, 1904, Supplément 7.

Teneriffe (Canaries), and St. Vincent (Cape Verdes). Since these balloons were only intended to show the atmospheric drift, they did not carry self-recording instruments, and their direction and velocity at increasing heights were determined from angular measurements at the ends of a base-line laid off on the lee shore of the islands mentioned. One balloon, carrying a self-recording barometer and thermometer, was launched from the yacht off the island of Palma (Canaries), but, though its drift was observed, the balloon could not be recovered. It was found possible sometimes to follow the balloons in the telescope until they reached a height of 11,000 or 12,000 meters.

The observations obtained with the kites at 500 and 1000 meters, and the simultaneous observations at sea-level, are given in Table I, which is divided into two parts, the first containing the observations made in an east-southeast direction across the Atlantic, and the second part those made in a southerly direction within the northeast trade and on its borders. West of the Azores, on the westerly slope of the permanent area of high barometric pressure, the observations between longitudes 69° and 39° show a slow decrease of temperature with increase of height, amounting to 4.5° per 1000 meters. In the lower 500 meters the decrease is only 0.24° per 100 meters, owing to inversions of temperature within the first few hundred meters in half the flights. In the next 500 meters there is the more rapid decrease of 0.66° per 100 meters. Upon the easterly and southeasterly slopes of the high pressure, between longitudes 25° and 19°, latitudes 38° and 33° north, the temperature falls at the adiabatic rate of one degree per 100 meters in the lower 500 meters, and then declines more slowly, namely, 0.20° per 100 meters, up to 1000 meters. The adiabatic rate appears to prevail over the ocean at night as well as in the daytime, and the bases of the cumulus clouds generally are not higher than 500 meters. The relative humidity decreases with height on the west of the high pressure, and increases to above 500 meters on the southeast side. In the former region southwest winds prevail, and in the latter locality northeast winds, the southwest winds turning to the left when facing them up to 500 meters, with increasing velocity up to 1000 meters, and the northeast winds turning to the right and increasing slightly in velocity up to 500 meters, but diminishing above that level. The mean directions and velocities in this table are resultants derived geometrically. In the column for wind-direction, a plus sign before the figures representing the differences per hundred meters indicates a turning towards the right hand, and a minus sign a turning towards the left.

The observations on the northern edge of the northeast trade, that is,

TABLE I.

Meteorological Conditions above the Atlantic.

1. *West and East of the Barometric Maximum, between Long. 69° and 16° W of Greenwich, Lat. 42° and 33° N.*

Date, 1905.	Place.		Temperature (C°).			Relative Humidity.			Wind Direction.			Wind Velocity (Meters per Second).		
	Lat. N.	Long. W.	0 Meters.	500 Meters.	1000 Meters.	0 Meters.	500 Meters.	1000 Meters	0 Meters.	500 Meters.	1000 Meters.	0 Meters.	500 Meters.	1000 Meters.
									°	°	°			
June 3	42	69	11.0	12.2	7.5	86	73	87	. .	. .	. .	. .	. .	. .
" 5	41	54	17.1	15.3	. .	85	73	. .	N 35 W	S 52 W	. .	6.0	2.0	. .
" 6	41	47	15.8	15.3	13.4	96	88	52	S 14 W	S 28 W	S 32 W	8.5	12 3	12.0
" 7	40	39	19.8	16.0	13.4	90	84	73	S 9 W	S 0	S 20 W	5.5	8.5	5.7
Mean	41	52	15.9	14.7	11.4	89	79	71	S 60 W	S 20 W	S 28 W	6.6	7.3	9.0
Δ 100 m.	. .	. .	. .	−.24	−.66	. .	−2.0	−1.6		−8	+2	. .	+.14	+.34
June 9	38	25	16.4	12.0	. .	57	83	. .	N 13 W	N 24 W	. .	10.0	13.3	. .
" 10	38	19	17.5	12.5	9.8	68	78	60	. .	. .	. .	. .	. .	. .
July 3	33	16	23.0	16.7	13.3	71	88	100	N 28 E	N 45 E	N 50 E	8.0	10.0	10.7
" 4	33	16	20.8	16.0	16.3	. .	. .	. .	N 28 E	N 2 E	N 8 W	7.0	8.3	6.5
Mean	35	19	19.4	14.3	13.1	65	83	80	N 12 E	N 23 E	N 28 E	7.8	8.3	7.5
Δ 100 m.	. .	. .	. .	−1.02	−.22	. .	+3.6	−.6	. .	+2	+1	. .	+.10	−.16

2. *Within the Northeast Trade and North and South of it, between Lat. 36° and 10° N, Long. 17° and 30° W.*

Aug. 20	36	24	23.2	18.9	. .	84	96	. .	N 56 E	N 56 E		. .	7.0	7.0	. .
" 19 P.	35	22	23.8	19.1	15.9	80	93	90	N 56 E	N 56 E	N 56 E	8.0	7.1	13.5
" " A.	35	19	23.6	19.0	14.7	79	92	96	N 64 E	N 54 E	N 64 E	7.0	6.8	10.0
" 18 P.	34	17	23.7	18.8	16.5	84	94	92	N 33 E	N 26 E	N 38 E	6.0	6.0	5.5
" " A.	34	19	23.2	18.3	15.8	83	94	90	N 38 E	N 45 E	N 50 E	8.0	10.0	10.7
Mean	35	20	23.5	18.8	15.7	82	94	92	N 50 E	N 48 E	N 54 E	7.0	7.0	9.5
Δ 100 m.	. .	. .	. .	−.92	−.62	. .	+2.4	−.4	. .	0	+1	. .	.00	+.50
Aug. 14	31	17	21.7	16.8	23.7	85	100	18	N 6 E	N 19 E	N 27 W	13.0	14.0	5.0
" 8	28	19	23.5	25.6	. .	67	29	. .	N 67 E	N 84 E	. .	1.6	2.2	. .
" 9	28[1]	17	23.2	19.8	23.9	72	58	41	SE	Calm	Calm	1.0	0	0
" 10	28[1]	17	23.6	22.7	21.1	82	86	85	NE	NE	Calm	3.0	1.3	0
July 12	27	17	20.3	20.0	28.9	84	67	7	. .	. .	. .	. .	. .	. .
Aug. 4	24	20	23.0	18.3	19.0	76	93	52	N 28 E	N 30 E	N 60 E	8.0	8.7	9.0
July 15	19	23	22.7	19.4	22.6	89	73	52	. .	. .	. .	. .	. .	. .
" 20 P.	16	26	24.3	19.5	21.2	83	87	48	N 50 E	N 45 E	N 57 E	6.0	6.0	10.5
" " A.	16	26	23.4	18.1	. .	90	99	. .	. .	. .	. .	. .	. .	. .
" 27	15[2]	24	25.7	21.7	28.2	68	83	13	E	var.	NE	8.0	1.7	9.5
" 28	15[2]	24	25.2	22.8	20.5	60	66	66	N	var.	S	7.0	3.0	1.5
Mean	22	22	23.3	20.4	23.2	78	77	42	N 30 E	N 32 E	N 44 E	4.2	4.3	5.6
Δ 100 m.	. .	. .	. .	−.58	+.56	. .	−.2	−.7	. .	0	+3	. .	.00	+.26
July 24	11	26	26.0	21.7	18.7	83	96	93	N	. .	N	3.0	. .	5.0
" 22	10	30	24.0	20.5	18.0	96	100	100	S 35 W	S 35 W	S 35 W	. .	. .	. .
Mean	10	28	25.0	21.1	18.3	89	98	96	. .		. .	. .	. .	. .
Δ 100 m.	. .	. .	. .	−.78	−.56	. .	+2.2	−.4	. .		. .	. .	. .	. .

[1] Peak of Teneriffe.

[2] Peak of Fogo.

between latitudes 36° and 34° north, show a rapid fall of temperature with height (7.8° per 1000 meters) which is fastest (0.92° per 100 meters) within the first 500 meters. The relative humidity rises nearly to saturation within the first 500 metres, but does not attain this point, the flat cumulus clouds found in the region being probably formed by the condensation of water-vapor rising from the ocean through a slow motion of diffusion. The wind, which is generally northeast, changes its direction but little with altitude, although it increases in velocity above 500 meters. The same features are shown by the only two observations south of the northeast trade, in about latitude 10° north. Within the trade-wind region, between latitudes 31° and 15°, the vertical distribution of temperature and moisture is quite different. Near its origin the trade has the character of a descending current, that is, small vapor contents and little cloud, which is the flat cumulus typical in northern regions of high pressure and descending air. In approaching the equator, that is, south of latitude 24° north, the trade presents characteristics of an ascending current, the relative humidity increases much with height, the sky is cloudy, and there are frequent rains, often accompanied by thunder-storms. The decrease of temperature within the trade region is less than 1° C. in 1000 meters, there being a fall of 0.58° in the first 500 meters and a rise of 0.56° in the next 500, on account of the inverted temperature-gradients which occur near 1000 meters at the upper limit of the trade-wind. Its depth varies from day to day between 300 and 1500 meters, and appears to be greatest in the afternoon and least at night. The upper portion is damp, with cumulus and strato-cumulus cloud, above which the wind falls light and the relative humidity sinks nearly to zero, coinciding with the rise in temperature, which frequently carries it much above that at sea-level. With increasing altitude there is a gradual shifting of the wind, when facing it, to the right, accompanied by an accelerated velocity, up to at least 1000 meters. The conditions at greater heights were deduced by Mr. Clayton as follows: Above the surface-trade is a current some 2000 meters in depth, varying in direction between northeast and northwest, but coming always from a direction to the left of the lower wind when facing it. This current is extremely dry and potentially warm, and its velocity usually much exceeds that of the lower wind. The third stratum, which begins at a height of about 3000 meters, moves from east, south or southwest, being generally from the east in equatorial regions, and from the south between latitudes 15° and 30° north (see Table II). As observed on the Peak of Teneriffe this stratum was dry in its lower portion, but with a larger vapor contents than the air immediately below. Alto-

TABLE II.

WINDS ABOVE THE TRADE-WIND REGION OF THE ATLANTIC, BETWEEN LAT. 37° AND 10° N, LONG. 15° AND 26° W OF GREENWICH.

1905.		
Aug. 22	St. Michaels (Azores)	NE to 800 meters; NW to at least 4200 meters.
" "	Madeira	WNW to 1800 m.; NW and SW to 11,500 m.; SW at 11,600 m.
" "	"	NE to 2900 m.; NW and NE to 4200 m.; WSW to at least 12,500 m.
July 17	Teneriffe (Canaries)	NE trade to 400 m.; NW to 3500 m.; WSW to at least 7500 m.
" 9	"	NE trade (variable) to 2000 m.; NNW to 4000 m.; SSE and SW to at least 5700 m.
" 10	"	NE trade to 3300 m.; SW and NW to 5200 m.; S and SE to at least 11,000 m.
Aug. 10	"	NE trade to 3200 meters; SE and S to 5300 m.; SSW to at least 5900 m.
" 11	"	NE trade to 2300 m.; S and SSW to at least 3900 m.
" 9–10	Peak of Teyde (Teneriffe)	E, 1 m. per sec., to 1000 m.; N, 4 m. per sec., at 2000 m.; N, 7 m. per sec., at 2500 m.; E, 3 m. per sec., at 3000 m.; S, 4 m. per sec., at 3500 m.; S at 4000 m. (?)
Aug. 13	At sea off Palma (Canaries)	NE trade to 2600 m.; NW to 3400 m.; WSW at 3400–4200 m.; SW to at least 6500 m.
July 17	St. Vincent (Cape Verdes)	NE trade (variable) to 4100 m.; variable to 5100 m.; SE and SSE to at least 11,000 m.
" 18	"	NE trade to 1300 m.; ESE to at least 2360 m.
" 29	"	NE trade to 650 m.; NW (variable) to 1900 m.; SW and SSW to 7500 m.; ESE and NE to 11,700 m.; S to at least 13,600 m.
" 27–28	Peak of Fogo (Cape Verdes)	E, 7–3 m. per sec., to 500 m.; NE, 6 m. per sec., at 1000 m.; N, 6 m. per sec., at 1500 m.; N, 5 m. per sec., at 2000 m.; ENE at 2500 m.; E at 3500 m. (?)
" 25	Lat. 13° N, Long. 24° W	NE, 4–3 m. per sec., to 1000 m.; E, 16 m. per sec., to 2500 m.
" 24	Lat. 11° N, Long. 26° W	N, 3–5 m. per sec., to 1600 m.; E at 3000 m. (?) by ACu clouds; ESE at 11,000 m. (?) by CiS clouds.

cumulus and alto-stratus clouds were seen floating in it at a height of perhaps 4000 or 5000 meters, and from them light sprinkles of rain fell occasionally. On the Peak of Teneriffe, in passing into this upper current, a rise of temperature was noted, which was less than that encountered above the surface-trade.

The winds at great heights in and near the trade-wind region are given in Table II. They were obtained by pilot-balloons launched from the islands, excepting the one from the yacht, and the last figures for each ascension show the maximum height at which the balloon was sighted. The means of direct observations of wind-direction and velocity at definite heights, obtained during the ascents and descents of the peaks on the tropical islands of Teneriffe and Fogo, and the drift of clouds passing at estimated heights above these mountains, are given. Observations of the direction and velocity of the wind, obtained in two kite-flights south of the trade-wind region, complete the table. In that portion of the Atlantic investigated by the Franco-American Expedition, the atmospheric circulation was found to be as follows: (1) North of Madeira, and near the Azores, the upper winds, as was already known by observations of clouds, are chiefly from west and northwest, this region being generally to the north of the barometric maximum over the ocean and beyond the zone of the trades. (2) The winds blowing towards the equator are from northeast to east in the lower region, and generally from northwest to northeast above 1000 meters. (3) The return currents from the equator, or anti-trades, are formed by winds having a southerly component, being generally southwest in the latitude of the Canaries, and southeast near the Cape Verdes, thus showing the influence of the earth's rotation. The law of the vertical succession of winds, as formulated by Abercromby, [5] namely, a shifting in the northern hemisphere of the upper winds to the left-hand, when one's back is towards the wind, is found not to hold true always, the right or left-handed rotation depending upon the origin of the wind, and, presumably, upon the distribution of the pressure at high levels.

The vertical distribution of temperature and relative humidity revealed by these observations up to a height of 4000 meters is nearly the same as that found by Professor Hergesell during the cruises of the "Princesse-Alice," in 1904 and 1905. [6] Most of his observations

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[5] Nature, **36**, 85.

[6] Comptes Rendus de l'Académie des Sciences, 30 janvier, 1905; Meteorologische Zeitschrift, November, 1905; Bulletin du Musée Océanographique de Monaco, 30 novembre, 1905.

of direction of the upper currents differ radically, however, in showing no southerly component, although one balloon, launched west of the Canaries, gave the same direction as that obtained near these islands, meeting interlaced currents from the southeast and southwest, above the northeast trade. From the distribution of pressure on the earth's surface it would be supposed that the upper antitrade ought to be especially regular in the region between Cape Verde and the Canaries; but this idea is contrary to the belief of Professor Hergesell that the upper southeast and southwest winds observed near these islands, and long considered to furnish a demonstration of the return-trade, are due to local disturbing causes. To settle this question, Messrs. Teisserenc de Bort and the author again sent the "Otaria," during the winter of 1906, to the south and west of the region which had been explored by them the preceding summer. Since this paper was presented to the Academy, Messrs. Maurice and Nilsson, constituting the scientific staff of the "Otaria," have communicated the results of their atmospheric soundings, made from the vessel to the westward of the Canaries, and these results appear in Table III. The longitudes are from Greenwich.

TABLE III.

WINDS OBSERVED IN FEBRUARY, 1906, ABOVE THE ATLANTIC, SOUTHWEST OF THE CANARIES.

Feb. 13	Lat. 28° N, Long. 18° W. ENE to 2850 m., NW to 3680 m., SW to the culminating point of the balloon, 5300 m.
" "	Lat. 27° N, Long. 18° W. ENE to 1800 m., SSE to 2100 m., N to 2250 m., SW to 2500 m., NW stratum 500 m. thick, then SW to 5100 m.
" 14	Lat. 26° N, Long. 19° W. NE changing to N up to 1350 m., NW to 2600 m., WSW and SW to 5100 m.
" "	Lat. 26° N, Long. 19° W. NE to 1300 m., NW and W to 3150 m., strong SW to 3300 m. Cirrus clouds (4 observations) from S 50° W.
" 15	Lat. 25° N, Long. 20° W. NE to 2300 m., NW to 3000 m., SW to 3250 m., WNW changing to W up to 3950 m., SW to 4150 m. Alto-cumulus clouds from NE, cirrus (2 observations) from S 30° W.
" 16	Cirrus clouds from S 45° W.

It is seen that the upper anti-trade is shown both by the balloons and by the drift of the clouds, the stratified conditions giving place to the southerly wind between 3000 and 4000 meters. Therefore the classic observations of the return-trade, which were long ago made on the Peak of Teneriffe, indicate a general phenomenon, and agree with those obtained over the open ocean by the present expedition.